1.   An optical mode transformer comprising:

a substrate;

a lower waveguide cladding layer disposed on the substrate, the lower waveguide cladding layer having a first refractive index and an upper surface;

a waveguide core disposed on the upper surface of the lower waveguide cladding layer, the waveguide core having a long axis, the waveguide core having a second refractive index, the ratio of the second refractive index to the first refractive index being at least about 1.3, the waveguide core further having a first end optically coupled to a small beam port, a second end defining an intermediate beam port, and an upper surface;

side waveguide cladding disposed on the upper surface of the lower waveguide cladding layer adjacent to both sides of the waveguide core, the side waveguide cladding having a third refractive index, the ratio of the second refractive index to the third refractive index being at least about 1.3, the side waveguide cladding further having an upper surface; and

an upper waveguide cladding layer disposed on the upper surface of the waveguide core and the upper surface of the side waveguide cladding, the upper waveguide cladding having a fourth refractive index, the ratio of the second refractive index to the fourth refractive index being at least about 1.3;

the optical mode transformer being configured such that the waveguide core has a vertical taper wherein a thickness of the waveguide core in a dimension normal to the substrate surface decreases along the long axis from a first thickness value at a first point near the small beam port to a second thickness value at a second point near the intermediate beam port, the second thickness value being smaller than a critical thickness value, the critical thickness value being defined as a thickness value below which a significant portion of the energy of a light beam having a small mode size received at the small beam port and propagating in the waveguide core penetrates into at least one of the upper waveguide cladding layer and the lower waveguide cladding layer, thereby enlarging the small mode size.

2.   An optical mode transformer for guiding a light beam and transforming a mode size of the light beam, the optical mode transformer having a small beam port at a small-beam end and a large beam port at a large-beam end, the optical mode transformer comprising:

5 a substrate;

6 a lower waveguide cladding layer disposed on the substrate, the lower
7 waveguide cladding layer having a first refractive index and an upper surface;

8 a waveguide core disposed on the upper surface of the lower
9 waveguide cladding layer, the waveguide core having a long axis and having a cross section
10 in a plane normal to the long axis, the waveguide core having a second refractive index, the
11 ratio of the second refractive index to the first refractive index being at least about 1.3, the
12 waveguide core further having a first end optically coupled to the small beam port, a second
13 end defining an intermediate beam port, and an upper surface;

14 side waveguide cladding disposed on the upper surface of the lower
15 waveguide cladding and adjacent to the waveguide core, the side waveguide cladding having
16 a third refractive index, the ratio of the second refractive index to the third refractive index
17 being at least about 1.3, the side waveguide cladding further having an upper surface; and

18 an upper waveguide cladding disposed on the upper surface of the
19 waveguide core and the upper surface of the side waveguide cladding, said upper waveguide
20 cladding having a fourth refractive index, the ratio of the second refractive index to the fourth
21 refractive index being at least about 1.3;

22 the optical mode transformer being configured such that:

23 in a first region along the long axis between the small beam
24 port and a transition point, the waveguide core cross section has a thickness in a dimension
25 normal to the substrate surface that is substantially constant and equal to a first thickness
26 value;

27 in a second region along the long axis between the transition
28 point and the intermediate beam port, the waveguide core cross section has a thickness that
29 changes along the long axis from the first thickness value to a second thickness value smaller
30 than the first thickness value, the second thickness value being smaller than a critical
31 thickness value, the critical thickness value being defined as a thickness value below which a
32 significant portion of the energy of a light beam having a small mode size received at the
33 small beam port and propagating in the waveguide core penetrates into at least one of the
34 upper waveguide cladding layer and the lower waveguide cladding layer, thereby enlarging
35 the small mode size; and

36 in a third region along the long axis between the intermediate
37 beam port and the large beam port, the waveguide core cross section has a thickness that is
38 substantially constant and approximately equal to the second thickness value.

1   3.   The optical mode transformer of claims 1 or 2, wherein the second
2 thickness value is substantially equal to zero.

1   4.   The optical mode transformer of claims 1 or 2, wherein the thickness
2 of the waveguide core changes substantially uniformly from the first thickness value to the
3 second thickness value.

1   5.   The optical mode transformer of claims 1 or 2, wherein the substrate
2 comprises silicon.

1   6.   The optical mode transformer of claims 1 or 2, wherein the waveguide
2 core comprises silicon.

1   7.   The optical mode transformer of claims 1 or 2, wherein the lower
2 waveguide cladding comprises silicon dioxide.

1   8.   The optical mode transformer of claims 1 or 2, wherein each of the
2 side waveguide cladding and the upper waveguide cladding comprises a mixture of silicon
3 dioxide and titanium dioxide.

1   9.   The optical mode transformer of claim 2, wherein a light beam having
2 an initial mode size enters the waveguide core from the small beam port and exits at the large
3 beam port having a final mode size larger in a dimension normal to the substrate surface than
4 the initial mode size.

1   10.   The optical mode transformer of claim 2, wherein a light beam having
2 an initial mode size enters at the large beam port and exits the waveguide core at the small
3 beam port having a final mode size smaller in a dimension normal to the substrate surface
4 than the initial mode size.

1   11.   The optical mode transformer of claims 1 or 2, wherein the waveguide
2 core further has a lateral taper along the direction of light propagation, wherein a width of
3 the waveguide core in a dimension parallel to the substrate surface and transverse to the
4 direction of light propagation increases from a first width to a second width, the second width
5 being substantially equal to a desired large mode size of a light beam.

1   12.   The optical mode transformer of claims 1 or 2, wherein the waveguide

2   core further has a lateral taper along the direction of light propagation, wherein a width of the

3   waveguide core decreases from a first width value to a second width value, the second width

4   value being smaller than a critical width value, the critical width value being defined as a

5   width value below which a significant portion of the energy of a light beam having a small

6   mode size received at the small beam port and propagating in the waveguide core penetrates

7   into the side waveguide cladding, thereby enlarging the small mode size.

1   13.   An optical mode transformer comprising:

2   a substrate;

3   a lower waveguide cladding layer disposed on the substrate and having

4   a first refractive index and an upper surface;

5   a waveguide core disposed on the upper surface of the lower

6   waveguide cladding layer, the waveguide core having a long axis, the waveguide core having

7   a second refractive index, the ratio of the second refractive index to the first refractive index

8   being at least about 1.3, the waveguide core further having a first end optically coupled to a

9   small beam port, a second end defining an intermediate beam port, and an upper surface;

10   side waveguide cladding disposed on the upper surface of the lower

11   waveguide cladding layer adjacent to both sides of the waveguide core, the side waveguide

12   cladding having a third refractive index, the ratio of the second refractive index to third

13   refractive index being at least about 1.3, the side waveguide cladding further having an upper

14   surface; and

15   an upper waveguide cladding layer disposed on the upper surface of

16   the waveguide core and the upper surface of the side waveguide cladding, the upper

17   waveguide cladding having a fourth refractive index, the ratio of the second refractive index

18   to the fourth refractive index being at least about 1.3;

19   the optical mode transformer being configured such that the waveguide

20   core has a lateral taper wherein a width of the waveguide core in a dimension parallel to the

21   substrate surface and transverse to the long axis decreases along the direction of light

22   propagation from a first width value at a first point near the small beam port to a second

23   width value at a second point near the intermediate beam port, the second width value being

24   smaller than a critical width value, the critical width value being defined as a width value

25   below which a significant portion of the energy of a light beam having a small mode size

26 received at the small beam port and propagating in the waveguide core penetrates into the
27 side waveguide cladding, thereby enlarging the small mode size.

1   14.   An optical mode transformer comprising:
2   a substrate;
3   a lower waveguide cladding layer disposed on the substrate and having
4 a first refractive index and an upper surface;
5   a waveguide core disposed on the upper surface of the lower
6 waveguide cladding layer, the waveguide core having a long axis and having a cross section
7 in a plane normal to the long axis, the waveguide core having a second refractive index, the
8 ratio of the second refractive index to the first refractive index being at least about 1.3, the
9 waveguide core further having a first end optically coupled to a small beam port, a second
10 end defining an intermediate beam port, and an upper surface;
11   side waveguide cladding disposed on the upper surface of the lower
12 waveguide cladding and adjacent to the waveguide core, the side waveguide cladding having
13 a third refractive index, the ratio of the second refractive index to the third refractive index
14 being at least about 1.3, the side waveguide cladding further having an upper surface; and
15   an upper waveguide cladding disposed on the upper surface of the
16 waveguide core and the upper surface of the side waveguide cladding, said upper waveguide
17 cladding having a fourth refractive index, the ratio of the second refractive index to the fourth
18 refractive index being at least about 1.3;
19   the optical mode transformer being configured such that:
20   in a first region along the long axis between the small beam
21 port and a transition point, the waveguide core cross section has a width that is substantially
22 constant and equal to a first width value;
23   in a second region along the long axis between the transition
24 point and the intermediate beam port, the waveguide core cross section has a width in a
25 dimension parallel to the substrate surface and transverse to the long axis that changes along
26 the long axis from the first width value to a second width value smaller than the first width
27 value, the second width value being smaller than a critical width value, the critical width
28 value being defined as a width value below which a significant portion of the energy of a
29 light beam having a small mode size received at the small beam port and propagating in the
30 waveguide core penetrates into the side waveguide cladding, thereby enlarging the small
31 mode size; and

32   in a third region along the long axis between the intermediate

33   beam port and a large beam port, the waveguide core cross section has a width that is

34   substantially constant and approximately equal to the second width value.

1   15.   The optical mode transformer of claims 13 or 14, wherein the second

2   width value is substantially equal to zero.

1   16.   The optical mode transformer of claims 13 or 14, wherein the width of

2   the waveguide core changes substantially uniformly from the first width value to the second

3   width value.

1   17.   The optical mode transformer of claims 13 or 14, wherein the substrate

2   comprises silicon.

1   18.   The optical mode transformer of claims 13 or 14, wherein the

2   waveguide core comprises silicon.

1   19.   The optical mode transformer of claims 13 or 14, wherein the lower

2   waveguide cladding comprises silicon dioxide.

1   20.   The optical mode transformer of claims 13 or 14, wherein each of the

2   side waveguide cladding and the upper waveguide cladding comprises a mixture of silicon

3   dioxide and titanium dioxide.

1   21.   The optical mode transformer of claim 14, wherein a light beam having

2   an initial mode size enters the waveguide core form the small beam port and exits at the

3   large beam port, having a final mode size larger in a dimension parallel to the substrate

4   surface and transverse to the direction of light propagation than the initial mode size.

1   22.   The optical mode transformer of claim 14, wherein a light beam having

2   an initial mode size enters the waveguide core from the large beam port and exits at the

3   small beam port having a final mode size larger in a dimension parallel to the substrate

4   surface and transverse to the direction of light propagation than the initial mode input beam.

1   23.   The optical mode transformer of claims 13 or 14, wherein the

2   waveguide core further has a vertical taper along the direction of light propagation, wherein

3   a thickness of the waveguide core in a dimension normal to the substrate surface increases

4   from a first thickness to a second thickness, wherein the second thickness is approximately

5   equal to a desired large mode size of a light beam.

1   24.   The optical mode transformer of claims 13 or 14, wherein the

2   waveguide core has a vertical taper along the direction of light propagation, wherein a

3   thickness of the waveguide core in a dimension normal to the substrate surface decreases

4   from a first thickness value to a second thickness value, the second thickness value being

5   smaller than a critical thickness value, the critical thickness value being defined as a

6   thickness value below which a significant portion of the energy of a light beam having a

7   small mode size received at the small beam port and propagating in the waveguide core

8   penetrates into at least one of the upper waveguide cladding layer and the lower waveguide

9   cladding layer, thereby enlarging the small mode size.

1   25.   An optical mode transformer comprising:

2   a substrate;

3   a lower waveguide cladding layer disposed on the substrate and having

4   a first refractive index, an upper surface and side surfaces;

5   a waveguide core disposed on the upper surface of the lower

6   waveguide cladding layer, the waveguide core having a long axis, the waveguide core having

7   a second refractive index, the ratio of the second refractive index to the first refractive index

8   being at least about 1.3, the waveguide core further having a first end optically coupled to a

9   small beam port, a second end defining an intermediate beam port, and an upper surface;

10   side waveguide cladding disposed on the side surfaces of the lower

11   waveguide cladding layer adjacent to both sides of the waveguide core, the side waveguide

12   cladding having a third refractive index, the ratio of the second refractive index to the third

13   refractive index being at least about 1.3, the side waveguide cladding further having an upper

14   surface; and

15   an upper waveguide cladding layer disposed on the upper surface of

16   the waveguide core and the upper surface of the side waveguide cladding, the upper

17   waveguide cladding having a fourth refractive index, the ratio of the second refractive index

18   to the fourth refractive index being at least about 1.3;

19   the optical mode transformer being configured such that the waveguide

20   core has a lateral taper wherein a width of the waveguide core in a dimension parallel to the

21   substrate surface and transverse to the long axis increases along the direction of light

22   propagation from a first width value at a first point near the small beam port to a second

23   width value at a second point near the intermediate beam port, the second width value being

24   substantially equal to a desired value that defines a large mode size of a light beam.

1   26.   An optical mode transformer comprising:

2   a substrate;

3   a lower waveguide cladding layer disposed on the substrate and having

4   a first refractive index, an upper surface and side surfaces;

5   a waveguide core disposed on the upper surface of the lower

6   waveguide cladding layer, the waveguide core having a long axis and having a cross section

7   in a plane normal to the long axis, the waveguide core having a second refractive index, the

8   ratio of the second refractive index to the first refractive index being at least about 1.3, the

9   waveguide core further having a first end optically coupled to a small beam port, a second

10   end defining an intermediate beam port, and an upper surface;

11   side waveguide cladding disposed on the side surfaces of the lower

12   waveguide cladding and adjacent to the waveguide core, the side waveguide cladding having

13   a third refractive index, the ratio of the second refractive index to the third refractive index

14   being at least about 1.3, the side waveguide cladding further having an upper surface; and

15   an upper waveguide cladding disposed on the upper surface of the

16   waveguide core and the upper surface of the side waveguide cladding, said upper waveguide

17   cladding having a fourth refractive index, the ratio of the second refractive index to the fourth

18   refractive index being at least about 1.3;

19   the optical mode transformer being configured such that:

20   in a first region along the direction of light propagation

21   between the small beam port and a transition point, the waveguide core cross section has a

22   width in a dimension parallel to the substrate surface and transverse to the long axis that is

23   substantially constant and equal to a first width value;

24   in a second region along the direction of light propagation

25   between the transition point and the intermediate beam port, the waveguide core cross section

26   has a width that changes along the long axis from the first width value to a second width

27   value larger than the first width value, the second width value being substantially equal to a

28   desired value that defines a large mode size of a light beam; and

29   in a third region along the direction of light propagation

30   between the intermediate beam port and a large beam port, the waveguide core cross section

31   has a width that is approximately constant and equal to the second width value.

1   27.   The optical mode transformer of claims or , wherein the second width

2   value is substantially equal to a mode size of an optical fiber.

1   28.   The optical mode transformer of claims or , wherein the width of the

2   waveguide core changes substantially uniformly from the first width value to the second

3   width value.

1   29.   The optical mode transformer of claims 25 or 26, wherein the substrate

2   comprises silicon.

1   30.   The optical mode transformer of claims 25 or 26, wherein the

2   waveguide core comprises silicon.

1   31.   The optical mode transformer of claims 25 or 26, wherein the lower

2   waveguide cladding comprises silicon dioxide.

1   32.   The optical mode transformer of claims 25 or 26, wherein each of the

2   side waveguide cladding and the upper waveguide cladding comprises a mixture of silicon

3   dioxide and titanium dioxide.

1   33.   The optical mode transformer of claim 26, wherein a light beam having

2   an initial mode size enters the waveguide core from the small beam port and exits at the large

3   beam port having a final mode size larger in a dimension parallel to the substrate surface and

4   transverse to the direction of light propagation than the initial mode size.

1   34.   The optical mode transformer of claim 26, wherein a light beam having

2   an initial mode size enters the waveguide core at the large beam port and exits at the small

3   beam port having a final mode size smaller in a dimension parallel to the substrate surface

4   and transverse to the direction of light propagation than initial mode size.

1   35.   The optical mode transformer of claims 25 or 26, wherein the

2   waveguide core further has a vertical taper along the direction of light propagation, wherein a

3   thickness of the waveguide core in a dimension normal to the substrate surface to increase

4   from a first thickness value to a second thickness value, wherein the second thickness value is

5   approximately equal to a desired large mode size of a light beam.

1   36.   The optical mode transformer of claims 25 or 26, wherein the

2   waveguide core has a vertical taper along the direction of light propagation, wherein a

3   thickness of the waveguide core in a dimension normal to the substrate surface to decrease

4   from a first thickness value to a second thickness value, the second thickness being smaller

5   than a critical thickness value, the critical thickness value being defined as a thickness value

6   below which a significant portion of the energy of a light beam having a small mode size

7   received at the small beam port and propagating in the waveguide core penetrates into at least

8   one of the upper waveguide cladding layer and the lower waveguide cladding layer, thereby

9   enlarging the small mode size.

1   37.   An optical waveguide comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface;

4   a non-cylindrical waveguide core aligned in axial direction disposed on the

5   lower waveguide cladding; said waveguide core having a center and an outer border; and

6   an upper waveguide cladding disposed on the waveguide core,

7   the waveguide core having a refractive index having a value that is graded in

8   the y-coordinate and gradually decreases from a maximum effective refractive index at the

9   center of the core to a minimum effective refractive index at the outer border of said

10   waveguide core, the y-coordinate representing a distance from the substrate surface.

1   38.   The optical waveguide of claim 37, wherein said waveguide core has a

2   refractive index that is graded in the x-coordinate and gradually decreases from a maximum

3   effective refractive index at the center of the core to a minimum effective refractive index at

4   the outer border of said waveguide core, the x-coordinate representing a direction transverse

5   to said y-coordinate and perpendicular to said axial direction.

1   39.   The optical waveguide of claim 37, wherein said waveguide core has a

2   refractive index that is constant in the x-coordinate, the x-coordinate representing a direction

3   transverse to said y-coordinate and perpendicular to said axial direction.

1   40.   An optical waveguide comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface;

4   a non-cylindrical waveguide core aligned in an axial direction disposed on the

5   lower waveguide cladding; said waveguide core having a center and an outer border;

6   an upper waveguide cladding disposed on the waveguide core,

7   the waveguide core having a first refractive index distribution that is graded

8   in a first direction normal to the substrate surface and that gradually decreases from a

9   maximum effective refractive index at the center of the core to a first minimum effective

10   refractive index at the outer border of said waveguide core,

11   and wherein said waveguide core has a second refractive index distribution

12   that is graded in a second direction transverse to said first direction perpendicular to said

13   axial direction and that gradually decreases from said maximum effective refractive index at

14   the center of the core to a second minimum effective refractive index at the outer border of

15   said waveguide core.

1   41.   An optical waveguide comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface;

4   a non-cylindrical waveguide core aligned in an axial direction disposed on the

5   lower waveguide cladding; said waveguide core having a center and an outer border;

6   an upper waveguide cladding disposed on the waveguide core,

7   the waveguide core having a refractive index having a value that is graded in

8   the y-coordinate and gradually decreases from a maximum effective refractive index at the

9   center of the core to a minimum effective refractive index at the outer border of said

10   waveguide core, the y-coordinate representing a distance from the substrate surface,

11   and wherein said waveguide core has a refractive index that is constant in the

12   x-coordinate, the x-coordinate representing a direction transverse to said y-coordinate and

13   perpendicular to said axial direction.

1   42.   An optical waveguide comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface;

4   a non-cylindrical waveguide core aligned in axial direction disposed on the

5   lower waveguide cladding; said waveguide core having a center and an outer border; and

6   an upper waveguide cladding disposed on the waveguide core,

7   the waveguide core having a refractive index having a value that is constant in

8   the y-coordinate, the y-coordinate representing a distance from the substrate surface.

1   43.   The optical waveguide of claim 42, wherein said waveguide core has a

2   refractive index that is graded in the x-coordinate and gradually decreases from a maximum

3   effective refractive index at the center of the core to a minimum effective refractive index at

4   the outer border of said waveguide core, the x-coordinate representing a direction transverse

5   to said y-coordinate and perpendicular to said axial direction.

1   44.   The optical waveguide of claim 42, wherein said waveguide core has a

2   refractive index that is constant in the x-coordinate, the x-coordinate representing a direction

3   transverse to said y-coordinate and perpendicular to said axial direction.

1   45.   An optical waveguide comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface;

4   a non-cylindrical waveguide core aligned in axial direction disposed on the

5   lower waveguide cladding; said waveguide core having a center and an outer border; and

6   an upper waveguide cladding disposed on the waveguide core,

7   the waveguide core having a refractive index having a value that is constant in

8   the y-coordinate, the y-coordinate representing a distance from the substrate surface,

9   and wherein said waveguide core has a refractive index that is graded in the x-

10   coordinate and gradually decreases from a maximum effective refractive index at the center

11   of the core to a minimum effective refractive index at the outer border of said waveguide

12   core, the x-coordinate representing a direction transverse to said y-coordinate and

13   perpendicular to said axial direction.

1   46.   An optical waveguide comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface;

4   a non-cylindrical waveguide core aligned in axial direction disposed on the

5   lower waveguide cladding; said waveguide core having a center and an outer border; and

6   an upper waveguide cladding disposed on the waveguide core,

7   the waveguide core having a refractive index having a value that is constant in

·8   the y-coordinate, the y-coordinate representing a distance from the substrate surface,

9   and wherein said waveguide core has a refractive index that is constant in the
10   x-coordinate, the x-coordinate representing a direction transverse to said y-coordinate and
11   perpendicular to said axial direction.

1   47.   An optical mode transformer comprising:
2   a substrate having a substrate surface;
3   a lower waveguide cladding disposed on the substrate surface, the
4   lower waveguide cladding having a refractive index distribution that varies according to a
5   first function of a y-coordinate, the y-coordinate representing a distance from the substrate
6   surface, the first function having a maximum value and a minimum value, the lower
7   waveguide cladding further having an upper surface;
8   a waveguide core disposed on the upper surface of the lower
9   waveguide cladding, the waveguide core having a core refractive index, the ratio of the core
10   refractive index to the maximum value of the first function being at least about 1.3, the
11   waveguide core further having a first end located substantially at a small beam port, a second
12   end defining an intermediate beam port, and an upper surface; and
13   an upper waveguide cladding disposed on the upper surface of the
14   waveguide core and on the upper surface of the lower waveguide cladding, the upper
15   waveguide cladding having a refractive index distribution that varies as a second function of
16   a y-coordinate, the second function having a maximum value and a minimum value, the ratio
17   of the core refractive index to the maximum value of the second function being at least about
18   1.3;
19   the optical mode transformer being configured such that the waveguide
20   core has a vertical taper along the long axis, the vertical taper being a changing thickness of
21   the waveguide core in a dimension normal to the substrate surface, wherein the thickness
22   decreases along the long axis from a first thickness value at a first point near the small beam
23   port to a second thickness value at a second point near the intermediate beam port, the second
24   thickness value being less than a critical thickness value, the critical thickness value being
25   defined as a thickness value below which a significant portion of the energy of a light beam
26   having a small mode size received at the small beam port and propagating in the waveguide
27   core penetrates into at least one of the upper waveguide cladding layer and the lower
28   waveguide cladding layer, thereby enlarging the small mode size.

1   48.   The optical mode transformer of claim 47, further comprising a low
2 refractive index buffer layer between said waveguide core and said lower waveguide
3 cladding.

1   49.   The optical mode transformer of claim 47, further comprising a low
2 refractive index buffer layer between said waveguide core and said upper waveguide
3 cladding.

1   50.   An optical mode transformer comprising:
2   a substrate having a substrate surface;
3   a lower waveguide cladding disposed on the substrate surface, the
4 lower waveguide cladding having a refractive index distribution that varies according to a
5 first function of a y-coordinate, the y-coordinate representing a distance from the substrate
6 surface, the first function having a maximum value and a minimum value, the lower
7 waveguide cladding further having an upper surface;
8   a waveguide core disposed on the upper surface of the lower
9 waveguide cladding, the waveguide core having a core refractive index, the ratio of the core
10 refractive index to the maximum value of the first function being at least about 1.3, the
11 waveguide core further having a first end located substantially at a small beam port, a second
12 end defining an intermediate beam port, and an upper surface; and
13   an upper waveguide cladding disposed on the upper surface of the
14 waveguide core and on the upper surface of the lower waveguide cladding, the upper
15 waveguide cladding having a refractive index distribution that varies as a second function of
16 a y-coordinate, the second function having a maximum value and a minimum value, the ratio
17 of the core refractive index to the maximum value of the second function being at least about
18 1.3;
19   the optical waveguide being configured such that:
20   in a first region along the long axis between the small beam
21 port and a transition point, the waveguide core cross section has a thickness in a dimension
22 normal to the substrate surface that is substantially constant and equal to a first thickness
23 value;
24   in a second region along the long axis between the transition
25 point and the intermediate beam port, the waveguide core cross section has a thickness that
26 changes along the long axis from the first thickness value to a second thickness value smaller

27   than the first thickness value, the second thickness being small enough to cause a small mode

28   size of a small light beam received at the small beam port to propagate into at least one of the

29   upper waveguide cladding layer and the lower waveguide cladding layer, thereby enlarging

30   the small mode size; and

31   in a third region along the long axis between the intermediate

32   beam port and the large beam port, the waveguide core cross section has a thickness that is

33   substantially constant and approximately equal to the second thickness value.

1   51.   The optical mode transformer of claim 50, further comprising a low

2   refractive index buffer layer between said waveguide core and said lower waveguide

3   cladding.

1   52.   The optical mode transformer of claim 50, further comprising a low

2   refractive index buffer layer between said waveguide core and said lower waveguide

3   cladding.

1   53.   The optical mode transformer of claims 47 or 50, wherein:

2   the lower waveguide cladding comprises a first plurality of lower

3   cladding layers substantially parallel to the substrate, wherein each lower cladding layer has a

4   layer-specific refractive index that is a function of the y-coordinate; and

5   the upper waveguide cladding comprises a second plurality of upper

6   cladding layers, wherein each upper cladding layer has a layer-specific refractive index that is

7   a function of the y coordinate.

1   54.   The optical mode transformer of claims 47 or 50, wherein, for any

2   value of the y-coordinate:

3   the effective layer-specific refractive index of each of the first plurality

4   of lower cladding layers is higher than the layer-specific refractive index of the lower

5   cladding layer below; and

6   the effective layer-specific refractive index of each of the second

7   plurality of upper cladding layers is lower than the layer-specific refractive index of the upper

8   cladding layer below.

1   55.   The optical mode transformer of claims 47 or 50, wherein the layer-

2   specific refractive index of each of the first plurality of lower cladding layers forms a first

3   refractive-index distribution that is symmetric with a second refractive-index distribution

4   formed by the layer-specific refractive index of each of the second plurality of upper cladding

5   layers.

1   56.   The optical mode transformer of claims 47 or 50, wherein the first and

2   second distributions together comprise a substantially parabolic distribution.

1   57.   The optical mode transformer of claims 47 or 50, wherein the first

2   function has a substantially parabolic dependence on the y-coordinate and the second

3   function has a substantially parabolic dependence on the y-coordinate.

1   58.   The optical mode transformer of claims 47 or 50, wherein:

2   the difference between the maximum value of the first function and the

3   minimum value of the first function is not less than about 0.02; and

4   the difference between the maximum value of the second function and

5   the minimum value of the second function is not less than about 0.02.

1   59.   The optical mode transformer of claims 47 or 50, wherein:

2   the first function is a constant function of the y-coordinate; and

3   the upper waveguide cladding comprises a plurality of upper cladding

4   layers substantially parallel to the substrate, wherein each upper cladding layer has a layer-

5   specific refractive index that is a function of the x coordinate.

1   60.   The optical mode transformer of claims 47 or 50, wherein for any

2   value of the y-coordinate:

3   the first function is a stepwise function of the x-coordinate having

4   substantially a first value in a first range of x-coordinate values, substantially a second value

5   in a second range of x-coordinate values, and substantially the first value in a third range of

6   x-coordinate values, wherein the second value is higher than the first value and wherein the

7   waveguide core is located at a position having x-coordinate values within the second range,

8   wherein the x-coordinate is in the axial direction parallel to the surface of said optical mode

9   transformer and perpendicular to the propagation direction of the light through said optical

10   mode transformer.

1   61.   The optical mode transformer of claims 47 or 50, wherein the

2   waveguide core further has a lateral taper along the direction of light propagation, the lateral

3   taper causing a width of the waveguide core in a dimension parallel to the substrate surface

4   and transverse to the direction of light propagation to increase from a first width value to a

5   second width value, the second width value being substantially equal to a desired large mode

6   size of a light beam.

1   62.   The optical mode transformer of claims 47 or 50, wherein the

2   waveguide core has a lateral taper along the direction of light propagation, the lateral taper

3   causing a width of the waveguide core to decrease from a first width value to a second width

4   value, the second width value being smaller than a critical width value, the critical width

5   value being defined as a width value below which a significant portion of the energy of a

6   light beam having a small mode size received at the small beam port and propagating in the

7   waveguide core penetrates into the waveguide cladding, thereby enlarging the small mode

8   size.

1   63.   The optical mode transformer of claims 47 or 50, wherein:

2   a light beam having a small mode size enters the optical waveguide at

3   the small beam port, the small mode size being substantially equal to a mode size of a

4   semiconductor optical device;

5   the light beam is modified to have an intermediate mode size as it

6   passes through the second region; and

7   the light beam is further modified to have a large mode size as it passes

8   through the third region, the large mode size being substantially equal to a mode size of an

9   optical fiber.

1   64.   The optical mode transformer of claims 47 or 50, wherein:

2   a light beam having a large mode size enters the optical waveguide at

3   the large beam port, the large mode size being substantially equal to a mode size of an optical

4   fiber;

5   the light beam is modified to have an intermediate mode size as it

6   passes through the third region; and

7   the light beam is further modified to have a small mode size as it

8   passes through the second and first regions to the small beam port, the small mode size being

9   substantially equal to a mode size of a semiconductor optical device.

1   65.   The optical mode transformer of claims 47 or 50, wherein:

2   a recess is formed in the substrate near the small beam port, the recess

3   being configured for mounting of a semiconductor optical device in alignment with the small

4   beam port; and

5   a groove is formed in the substrate near the large beam port, the groove

6   being configured to hold an optical fiber in alignment with the large beam port.

1   66.   The optical mode transformer of claim 65, wherein a semiconductor

2   optical device is mounted in the recess.

1   67.   The optical mode transformer of claim 65, wherein an optical fiber is

2   mounted in the groove.

1   68.   The optical mode transformer of claims 47 or 50, wherein:

2   the first function and the second function are chosen such that the

3   upper and lower cladding provide a lens function in the third region, whereby a light beam

4   propagating from the small beam port to the large beam port is caused to be enlarged and

5   collimated.

1   69.   The optical mode transformer of claim 50, wherein:

2   the first function and the second function are chosen such that the

3   upper and lower cladding provide a lens function in the third region, whereby a light beam

4   propagating from the large beam port to the small beam port is caused to be reduced and

5   focused onto the intermediate beam port.

1   70.   An optical mode transformer comprising:

2   a substrate having a substrate surface;

3   a lower waveguide cladding disposed on the substrate surface, the

4   lower waveguide cladding having a vertical refractive index having a vertical value that

5   varies according to first substantially stepwise function of a y-coordinate, the y-coordinate

6   representing a distance from the substrate surface, the first function having a maximum value

7   and a minimum value, and the lower waveguide cladding having a horizontal refractive index

8   having a horizontal value that varies according to first substantially stepwise function of an x-

9   coordinate, the x-coordinate representing a position in a dimension parallel to the substrate

10   surface and transverse to the long axis, the first function having a maximum value and a

11   minimum value, the lower waveguide cladding further having an upper surface;

12   a waveguide core disposed on the upper surface of the lower
13 waveguide cladding, the waveguide core having a core refractive index, the ratio of the core
14 refractive index to the maximum value of the first function being at least about 1.3, the
15 waveguide core further having a first end located substantially at the small beam port, a
16 second end defining an intermediate beam port, and an upper surface; and
17   an upper waveguide cladding disposed on the upper surface of the
18 waveguide core and on the upper surface of the lower waveguide cladding, the upper
19 waveguide cladding having a refractive index having a value that varies as a second function
20 of the y-coordinate and of the x-coordinate, the second function having a maximum value and
21 a minimum value, the ratio of the core refractive index to the maximum value of the second
22 function being at least about 1.3;
23   the optical mode transformer being configured such that the waveguide
24 core has a vertical taper along the long axis, the vertical taper being a changing thickness of
25 the waveguide core in a dimension normal to the substrate surface, wherein the thickness
26 decreases along the long axis from a first thickness value at a first point near the small beam
27 port to a second thickness value at a second point near the intermediate beam port, the second
28 thickness value being less than a critical thickness value, the critical thickness value being
29 defined as a thickness value below which a significant portion of the energy of a light beam
30 having a small mode size received at the small beam port and propagating in the waveguide
31 core penetrates into at least one of the upper waveguide cladding layer and the lower
32 waveguide cladding layer, thereby enlarging the small mode size.

1   71.   An optical mode transformer comprising:
2   a substrate having a substrate surface;
3   a lower waveguide cladding disposed on the substrate surface, the
4   lower waveguide cladding having a vertical refractive index distribution that varies according
5   to first substantially stepwise function of a y-coordinate, the y-coordinate representing a
6   distance from the substrate surface, the first function having a maximum value and a
7   minimum value, and the lower waveguide cladding having a horizontal refractive index
8   distribution that varies according to first substantially stepwise function of an x-coordinate,
9   the x-coordinate representing a position in a dimension parallel to the substrate surface and
10 transverse to the long axis, the first function having a maximum value and a minimum value,
11 the lower waveguide cladding further having an upper surface;

12   a waveguide core disposed on the upper surface of the lower

13   waveguide cladding, the waveguide core having a core refractive index, the ratio of the core

14   refractive index to the maximum value of the first function being at least about 1.3, the

15   waveguide core further having a first end located substantially at a small beam port, a second

16   end defining an intermediate beam port, and an upper surface; and

17   an upper waveguide cladding disposed on the upper surface of the

18   waveguide core and on the upper surface of the lower waveguide cladding, the upper

19   waveguide cladding having a refractive index distribution that varies as a second function of

20   the y-coordinate and of the x-coordinate, the second function having a maximum value and a

21   minimum value, the ratio of the core refractive index to the maximum value of the second

22   function being at least about 1.3;

23   the optical mode transformer being configured such that:

24   in a first region along the long axis between the small beam

25   port and a transition point, the waveguide core cross section has a thickness in a dimension

26   normal to the substrate surface that is substantially constant and equal to a first thickness

27   value;

28   in a second region along the long axis between the transition

29   point and the intermediate beam port, the waveguide core cross section has a thickness that

30   changes along the long axis from the first thickness value to a second thickness value smaller

31   than the first thickness value, the second thickness being small enough to cause a small mode

32   size of a small light beam received at the small beam port to propagate into at least one of the

33   upper waveguide cladding layer and the lower waveguide cladding layer, thereby enlarging

34   the small mode size; and

35   in a third region along the long axis between the intermediate

36   beam port and a large beam port, the waveguide core cross section has a thickness that is

37   approximately constant and equal to the second thickness value.

1   72.   A method of fabricating an optical waveguide having a tapered

2   waveguide core using a silicon-on-insulator wafer having a silicon substrate layer, an

3   insulator layer, and a silicon upper layer, the method comprising:

4   depositing a photoresist layer on the silicon upper layer of the silicon-

5   on-insulator wafer;

6   applying a mask to the photoresist, the mask having a gray-scale mask

7   pattern that provides an exposure level that varies with position along a length of the mask;

8	exposing the photoresist and mask to radiation from a radiation source;
9	performing a selective etching procedure that etches the photoresist
10	and the silicon upper layer and does not substantially etch the insulator, the presence of the
11	photoresist during the selective etching procedure causing a vertically tapered shape to be
12	formed in the silicon upper layer; and
13	depositing an upper cladding layer over the top and sides of the
14	vertically tapered shape.

| 1 | 73. | The method of claim 72, wherein the radiation source comprises an |
| 2 | ultraviolet radiation source. |

| 1 | 74. | The method of claim 72, wherein the radiation source comprises an e- |
| 2 | beam source. |

1	75.	The method of claim 72, wherein the gray-scale mask pattern has a
2	tapered shape, the gray-scale mask pattern being wide at an end at which the gray scale is
3	darkest and narrow at an opposite end.

1	76.	The method of claim 72, wherein the gray-scale mask pattern has a
2	tapered shape, the gray-scale mask pattern being narrow at an end at which the gray scale is
3	darkest and wide at an opposite end.

1	77.	A method of fabricating an optical waveguide using a silica-on-silicon
2	wafer having a silicon substrate layer and a silica layer, the optical waveguide having a step
3	refractive index distribution in both a vertical and a lateral dimension, the method
4	comprising:
5	depositing a dielectric waveguiding film on the silica layer;
6	depositing a photoresist layer of said dielectric waveguiding film;
7	applying a photomask to the dielectric waveguiding film, the
8	photomask having a stripe defined therein;
9	exposing the photomask to ultraviolet radiation; and
10	dry-etching a stripe in the dielectric waveguiding film using a
11	photolithographic process.

1   78.   A method of fabricating an optical waveguide on a silicon substrate,
2 the optical waveguide having a step refractive index distribution in both a vertical and a
3 lateral dimension, the method comprising the steps of:
4   providing a silica-on-silicon wafer having a silicon substrate layer and
5 a silica layer;
6   depositing a photosensitive dielectric waveguiding film on the silica
7 layer;
8   applying a photomask to the photosensitive dielectric waveguiding
9 film, said photomask having a stripe defined therein; and
10   exposing the photosensitive dielectric waveguiding film to ultraviolet
11 radiation, thereby causing an index of refraction of the waveguiding film to be selectively
12 increased in an area corresponding to the stripe defined in the photomask.

1   79.   The method of claim 78, wherein the photosensitive dielectric
2 waveguiding film comprises a silica-based glass film with germanium or lead incorporated
3 therein.

1   80.   The method of claim 78, further comprising depositing a cladding
2 material over the dielectric waveguiding film.

1   81.   The method of claim 78, further comprising depositing a cladding
2 material over the photosensitive dielectric waveguiding film.

1   82.   The method of claim 81, wherein exposing the photosensitive
2 dielectric waveguiding film to ultraviolet radiation is performed after depositing a cladding
3 material over the photosensitive dielectric waveguiding film, and wherein the cladding
4 material comprises a material that does not substantially absorb ultraviolet radiation.

1   83.   A method of fabricating an optical waveguide on a silicon substrate,
2 the optical waveguide having a graded refractive index distribution in a vertical dimension
3 and a step refractive index distribution in a lateral dimension, the method comprising:
4   providing a silica-on-silicon wafer having a silicon substrate layer and
5 a silica layer;

6   successively depositing a first plurality of thin layers of dielectric

7   material on the silica layer, wherein each of the first plurality of thin layers of dielectric

8   material has an effective refractive index larger than a refractive index of the preceding layer;

9   successively depositing a second plurality of thin layers of dielectric

10   material, wherein each of the second plurality of thin layers of dielectric material has an

11   effective refractive index smaller than a refractive index of the preceding layer;

12   depositing a photoresist layer on said second plurality of thin layers of

13   dielectric material;

14   applying a photomask to the uppermost layer of dielectric material, the

15   photomask having a stripe defined therein;

16   exposing the photomask to ultraviolet radiation; and

17   dry-etching a stripe in the dielectric material using a photolithographic

18   process, thereby forming a waveguide channel.

1   84.   A method of fabricating an optical waveguide on a silicon substrate,

2   the optical waveguide having a graded refractive index distribution in a vertical dimension

3   and a step refractive index distribution in a lateral dimension, the method comprising:

4   providing a silica-on-silicon wafer having a silicon substrate layer and

5   a silica layer;

6   successively depositing a first plurality of thin layers of photosensitive

7   dielectric material on the silica layer, wherein each of the first plurality of thin layers of

8   photosensitive dielectric material has an effective refractive index larger than a refractive

9   index of the preceding layer;

10   successively depositing a second plurality of thin layers of dielectric

11   material, wherein each of the second plurality of thin layers of dielectric material has an

12   effective refractive index smaller than a refractive index of the preceding layer;

13   applying a photomask to the uppermost layer of photosensitive

14   dielectric waveguiding film, said photomask having a stripe defined therein; and

15   exposing the layers of photosensitive dielectric waveguiding film to

16   ultraviolet radiation, thereby causing the index of refraction of each of the layers of

17   photosensitive dielectric waveguiding film to be selectively increased in an area

18   corresponding to the stripe defined in the photomask.

1   85.   The method of claim 83, further comprising depositing a cladding
2 material over the uppermost layer of dielectric waveguiding film.

1   86.   The method of claim 84, further comprising depositing a cladding
2 material over the uppermost layer of photosensitive dielectric waveguiding film.

1   87.   A method of fabricating an optical waveguide on a silicon substrate,
2 the optical waveguide having a graded refractive index distribution in a vertical dimension
3 and a graded refractive index distribution in a lateral dimension, the method comprising :
4   providing a silica-on-silicon wafer having a silicon substrate layer and
5 a silica layer;
6   successively depositing a first plurality of thin layers of photosensitive
7 dielectric material on the silica layer, wherein each of the first plurality of thin layers of
8 photosensitive dielectric material has an effective refractive index larger than a refractive
9 index of the preceding layer;
10   successively depositing a second plurality of thin layers of dielectric
11 material, wherein each of the second plurality of thin layers of dielectric material has an
12 effective refractive index smaller than a refractive index of the preceding layer;
13   applying a photomask to the uppermost layer of photosensitive
14 dielectric waveguiding film, said photomask having a grayscale pattern defined therein; and
15   exposing the layers of photosensitive dielectric waveguiding film to
16 ultraviolet radiation, thereby causing the index of refraction of each of the layers of
17 photosensitive dielectric waveguiding film to be selectively increased in proportion to the
18 grayscale pattern defined in the photomask and producing a graded index of refraction along
19 the lateral dimension of each of the layers of photosensitive dielectric waveguiding film.

1   88.   A method of fabricating an optical waveguide on a silicon substrate,
2 the optical waveguide having a tapered high-refractive-index waveguide core and a cladding
3 having a graded refractive index distribution in a vertical dimension and a step refractive
4 index distribution in a lateral dimension, the method comprising:
5   providing a silica-on-silicon wafer having a silicon substrate layer and
6 a silica layer;
7   successively depositing a first plurality of thin layers of photosensitive
8 dielectric material on the silica layer, wherein each of the first plurality of thin layers of

108

9   photosensitive dielectric material has an effective refractive index larger than a refractive

10   index of the preceding layer;

11   bonding a silicon layer on the uppermost layer of the first plurality of

12   thin layers of photosensitive dielectric material;

13   depositing a photoresist layer on the silicon upper layer;

14   applying a first photomask to the photoresist, the first photomask

15   having a gray-scale mask pattern that provides an exposure level that varies with position

16   along a length of the first photomask;

17   exposing the photoresist and photomask to radiation from a radiation

18   source;

19   performing a selective etching procedure that etches the photoresist

20   and the silicon upper layer and does not substantially etch the insulator, the selective etching

21   procedure causing a vertically tapered shape to be formed in the silicon upper layer;

22   successively depositing a second plurality of thin layers of dielectric

23   material, wherein each of the second plurality of thin layers of dielectric material has an

24   effective refractive index smaller than a refractive index of the preceding layer;

25   applying a second photomask to the uppermost layer of photosensitive

26   dielectric waveguiding film, said second photomask having a stripe defined therein; and

27   exposing the layers of photosensitive dielectric waveguiding film to

28   ultraviolet radiation, thereby causing the index of refraction of each of the layers of

29   photosensitive dielectric waveguiding film to be selectively increased in an area

30   corresponding to the stripe defined in the second photomask.

1   89.   The optical mode transformer of claim 1, wherein the second end is

2   optically coupled to a large beam port, and wherein a light beam having an initial mode size

3   enters the waveguide core from the small beam port and exits at the large beam port having a

4   final mode size larger in a dimension normal to the substrate surface than the initial mode

5   size.

1   90.   The optical mode transformer of claim 1, wherein the second end is

2   optically coupled to a large beam port, and wherein a light beam having an initial mode size

3   enters at the large beam port and exits the waveguide core at the small beam port having a

4   final mode size smaller in a dimension normal to the substrate surface than the initial mode

5   size.

91.   The optical mode transformer of claim 13, wherein the second end is optically coupled to a large beam port, and wherein a light beam having an initial mode size enters the waveguide core form the small beam port and exits at the large beam port, having a final mode size larger in a dimension parallel to the substrate surface and transverse to the direction of light propagation than the initial mode size.

92.   The optical mode transformer of claim 13, wherein the second end is optically coupled to a large beam port, and wherein a light beam having an initial mode size enters the waveguide core from the large beam port and exits at the small beam port having a final mode size larger in a dimension parallel to the substrate surface and transverse to the direction of light propagation than the initial mode input beam.

93.   The optical mode transformer of claim 25, wherein the second end is optically coupled to a large beam port, and wherein a light beam having an initial mode size enters the waveguide core from the small beam port and exits at the large beam port having a final mode size larger in a dimension parallel to the substrate surface and transverse to the direction of light propagation than the initial mode size.

94.   The optical mode transformer of claim 25, wherein the second end is optically coupled to a large beam port, and wherein a light beam having an initial mode size enters the waveguide core at the large beam port and exits t at the small beam port having a final mode size smaller in a dimension parallel to the substrate surface and transverse to the direction of light propagation than initial mode size.

95.   The optical mode transformer of claims 1, 2, 13, 14, 36, 47 or 70, wherein the critical thickness value is defined as approximately $\lambda_0 / \left(4\sqrt{n_c^2 - n_{cl}^2} \right)$, where λ_0 is the wavelength of the light beam in a vacuum, where n_c is the refractive index of the waveguide core, and wherein n_{cl} is the index of refraction of the waveguide cladding.